Support Assemblies and Systems for Semi-Membrane Tanks

TECHNICAL FIELD

This invention relates to systems for supporting the sidewalls and tops of semi-membrane tanks used to store and transport liquids at temperatures substantially differing from ambient temperatures, including particularly for liquids such as liquefied natural gas (LNG), liquefied petroleum gas and anhydrous ammonia, which may be stored and transported at temperatures substantially below ambient temperature. The invention can also be applied to semi-membrane tanks for the containment of liquids stored and transported at temperatures substantially higher than ambient temperatures.

BACKGROUND

Semi-membrane tanks are not self-supporting. Their sidewalls require support from a surrounding support structure. U.S. Patent 5,727,492 describes semi-membrane tanks having sidewalls of curved-plate construction, although flat-plate construction with relatively light stiffening members may also be used for semi-membrane tanks. In either case a surrounding support structure is required. As described in U.S. Patent 5,727,492, surrounding support structure may include the inner hull of a double-hulled tanker or a grid of beams supporting a storage tank, for example, in a land-based facility. Semi-membrane tank sides and top are connected to the surrounding support structure through insulating supports or support assemblies.

The bottom of a semi-membrane tank normally is of flat-plate construction and rests on load-bearing insulation that in turn rests on underlying support structure. The tank bottom and load bearing insulation may be flat, as in one horizontal plane parallel to the underlying support structure or in several sloped planes oriented towards a fixed point to facilitate drainage. Typically the tank bottom will contract and expand about said fixed point which is normally located either at its geometric center or at another point vertically aligned with an expansion dome on the top of the tank. Such fixed point is typically maintained at a fixed location by a combination of structural keys affixed to the external surface of the tank bottom. The keys extend radially from said fixed point and mate with keyways in the load-bearing insulation normally oriented along the transverse and longitudinal axes of the tank. With changes in temperature as the tank is filled and

emptied, the tank bottom contracts and expands by sliding over the load bearing insulation against which it is held by gravity.

The temperature of the sidewalls of the tank and the tank top also deviate significantly from the normally ambient temperature of the surrounding support structure as the tank is filled. This thermal deviation causes shrinkage, if the tank is used for cold liquid, and tends to subject the tank to significant thermal stresses. The method of support between the tank and surrounding support structure will significantly influence the level and distribution of these thermal stresses.

Insulation systems typically are secured directly to tank surfaces after tank construction is substantially complete. Insulated support systems for semi-membrane tanks are typically attached directly to surrounding support structure which is made integral with longitudinal and transverse structure in the case of a shipboard installation.

Published U.S. Patent Application Publication No. 2003/0066834A1 describes an array of support assemblies for use in a support system for semi-membrane tank. The assemblies are the components intermediate to the tank walls and the surrounding support structure. Assemblies of that published patent application include three components or blocks: a first block rigidly attached to a tank wall, a second block rigidly attached to the surrounding support structure, and a third block intermediate to the first two. The third block slidingly engages the first block, permitting sliding movement along a first line parallel to the plane of the tank wall, and the third block slidingly engages the second block, permitting sliding movement along a second line, perpendicular to the first, also parallel to the plane of the tank wall. In combination, the two sliding movements permit orthogonal movement, in the plane of tank wall, of the tank wall relative to the support structure. The support system prevents inward and outward movement perpendicular to the sidewalls and top of the tank.

If one considers a rectangular tank having four sidewalls, a top and a bottom, it will be appreciated that unrestrained thermal contraction resulting from lowered temperatures causes each of those six members to contract in its plane. In effect the tank attempts to become smaller by pulling inwardly away from the surrounding support structure to which it is attached by a support system. Walls of semi-membrane tanks must have at least fixed points aligned with the fixed expansion dome projecting through

the top. Further, the walls and top, which are not self-supporting, must be supported vertically, and the walls must also be supported perpendicular to their respective planes. The support system of, for example, U.S. Patent Publication 2003/0066834A1 permits only contraction in the plane of each wall and prevents inward movement away from the support structure. Certain support assemblies are fixed against vertical movement of the walls and therefore, support the tank walls. The restriction against motion perpendicular to the plane of each wall imposes substantial thermal stresses at the edges where a tank wall meets the top, the bottom or another wall. These intersections must therefore be both sufficiently flexible to accommodate contraction and sufficiently robust to afford acceptable stress levels in the tank structural material. Flexibility is typically achieved by utilizing edges having substantial curved cross-sectional shapes that are capable of accepting considerable distortion as the tank contracts. The radius of curvature must be sufficiently large to permit such distortion without reaching unacceptable stress. The thickness of the structural material of the curved edges must be sufficiently thick and strong so as to prevent buckling and to maintain acceptable stress levels under all temperature conditions caused by the tank being full, empty or partially full. Small-radius curved edges of relatively lightweight construction are inadequate for this purpose, because of the magnitude of stress levels.

It is the object of the present invention to provide a support arrangement for semi-membrane tank walls and top that provides a thermally insulated structural attachment between the tank and its surrounding support structure that overcomes the disadvantages of existing arrangements and improves the efficiency of constructing and installing such tanks.

SUMMARY

An aspect of this invention is support assemblies that permit a wall or top of a semi-membrane tank to move in and out perpendicularly to the plane of the wall or top and simultaneously accommodate shrinkage and expansion of the wall or top in either one line in the plane of the wall or top or in perpendicular lines in that plane.

Deployment of support assemblies according to this invention in arrays across semi-membrane tank walls provides support for the walls, including needed vertical

support, while minimizing thermally induced stresses at edges formed by the intersection of a wall with the top, bottom or another wall.

Yet another aspect of the present invention is arrays of support assemblies that permit a reduction in the radius of curvature of tank edges as compared to existing systems discussed above, with a concomitant increase in tank volume, and that further permit a reduction in the amount of tank structural material, thereby simplifying construction and reducing construction costs.

Another aspect of the present invention is utilizing support assemblies to secure sheets or panels of tank insulation in place, for example, the use of flanged devices securing support assemblies to the tank in combination with flanged collars secured to the support assemblies to which insulation panels are secured to minimize heat transfer to the tank.

Yet another aspect of the present invention is a support system for the walls of a semi-membrane tank and, optionally, the tank bottom, that includes the surrounding support structure and means for slidingly engaging the surrounding support structure with an outer containment structure such as a tanker's inner hull or a shore installation's outer frame constructed on site, for example the attachment of vertical keys to the tank support systems for walls, which keys slidingly engage keyways attached to the surrounding ship structure. This aspect simplifies tank installation by securing the tank walls and bottom, for example, the surrounding ship structure by the simple act of engaging the keys and keyways as the surrounding support structure containing the tank is lowered into the ship's hull. Keys and keyways in the preferred embodiment are preferentially tapered in cross section and as well as vertically to facilitate engagement as the tank and surrounding support structure are lowered into the surrounding ship or shore-based structure.

A feature of this invention is that the walls and top are allowed a relatively minor deviation from plane at low temperature.

In this application and the appended claims, certain terms have the meanings that follow:

"Wall" means a vertically oriented sidewall of a semi-membrane tank. Walls of semi-membrane tanks are arranged in a geometric pattern, for example, a rectangular,

trapezoidal or hexagonal or cylindrical tank. Walls of such tanks are planar, if made of flat plates, or approximately planar, if constructed from curved plates. Such walls are referred to in this application variously as "flat" or "planar". A cylindrical tank has one continuous wall forming the cylinder.

"Plane of a wall" means the major planar outer surface at ambient temperature of a straight-sided wall of flat-plate construction or the vertical plane through the cusps joining curved plates in such a wall.

"Plane of a top" means the major planar outer surface of a tank top at ambient temperature.

"Surrounding support structure" is the structure to which support assemblies are attached away from the tank. Surrounding support structure may, or may not be integral with the outer containment structure such as the surrounding ship structure. Alternatively, surrounding support structure may be a lifting frame, a framework in which a tank is assembled. The surrounding support structure may be fitted with vertical keys which engage keyways integral with said outer containment structure, or vice versa, as a tank is lowered into its final location.

"Outer containment structure" is the structure outside surrounding support structure, if they are not one and the same.. For walls in a tanker installation it is commonly the inner longitudinal hull structure and the transverse hull bulkhead structure including bracing members attached thereto, and for the top it is commonly the main deck of a double hull tanker. Outer containment structure for walls in a shore installation is commonly a framework of interconnected beams extending upwardly from a concrete base on the ground.

"Ramp" means an angled surface projecting outwardly from the tank that slidingly engages a complementary surface supported by the surrounding support structure. This surface may be planar or may have one degree of curvature with its axis parallel to the angle of the ramp. Movement "along the ramp" means movement up or down the ramp parallel to the axial centerline of the ramp surface. Movement "across the ramp" or "cross-ramp" means movement parallel to the ramp surface but in a direction perpendicular to the axial centerline of the ramp surface, if the ramp surface is flat, or parallel to the chord of the arc of the surface, if the surface is curved. Movement up or

down a ramp can be broken into two perpendicular components of Cartesian coordinates, for example a component along an x axis and a component along a y axis. If a ramp is placed horizontally on a vertical surface, one component of movement parallel to the ramp is horizontal and parallel to the plane of the wall and the other component is also horizontal but perpendicular to the plane of the wall; and movement across the ramp is vertical and parallel to the plane of the wall. If a ramp is placed vertically on a vertical surface, one component of movement parallel to the ramp is vertical and parallel to the plane of wall or to the axis of the cylinder, if the tank is cylindrical, and the other component is horizontal but perpendicular to the plane of the wall or to the axis of the cylinder; and movement across the ramp is horizontal and parallel to the plane of the wall or the tangent of a cylindrical wall.

"Ramped away" from a point or line in a tank wall or top means for a support assembly that the member attached to the tank wall or top has a ramp surface acutely angled toward that point or line.

"Support assembly" means an assemblage of interlocked structural components or members spaced between the tank wall or top and the surrounding support structure that together allow for attachment of the wall or top to the surrounding support structure.

Support assemblies according to this invention permit a tank wall or top to move relative to the surrounding support structure in at least two directions, namely, in one direction perpendicular to the plane of the wall or top or to the axis of the cylinder of a cylindrical wall, that is, inwardly away from the support structure as the tank shrinks and outwardly toward the support structure as the tank expands; and in at least one direction parallel to the plane of the wall or top or to the axis of the cylinder of a cylindrical wall, that is, toward a fixed point or a line in the plane of the wall or toward the axis of the cylinder as the wall or top shrinks and away from such a point as the tank expands. Movement in two directions is accomplished by means of a "two dimension" support assembly that is angled relative to those two directions of movement and permits movement along the ramp. As the wall or top shrinks in the plane of the wall or top, or as a cylindrical wall shrinks, the ramp attached to the wall or top translates relative to its complementary surface, thereby deflecting the ramp inwardly perpendicular to the plane of the wall or top or toward the axis of a cylindrical wall. By appropriately sizing the

ramping angle, appropriate inward deflection obtains for minimizing stress at points which otherwise would be subjected to the highest thermal stresses. Thus, a ramp near a fixed point, for example, the midpoint of a flat wall's length, will translate a shorter distance in the plane of the wall and thereby deflect a shorter distance perpendicular to that plane than will a ramp further out from said fixed point, thereby accommodating the greater amount of deflection of the latter as the tank shrinks. In this way positive inward support of a tank wall or top away from the surrounding support structure is maintained as the tank shrinks and expands while the tank wall or top is prevented from moving outwardly due to mechanical forces, such as rolling or pitching of a ship or the pressure of liquid cargo, at all temperatures. Calculating ramp angles is a matter of design based on the thermal properties of a wall or top and specific tank geometry and is within the skill of the art. Placed horizontally, two dimension support assemblies provide vertical support for the tank wall.

Other support assemblies according to this invention additionally permit movement in the plane of the wall or top perpendicular to the first direction. These assemblies, therefore, permit orthogonal movement in the plane of wall or top as well as movement perpendicular to the plane of the wall or top. The added degree of freedom of movement is provided by a "three dimension" support assembly.

Support assemblies according to this invention can be included in arrays of supports between tank walls or top and the surrounding support structure. Each array for a planar wall or top includes a "center of thermal fixity" which is either a point of rigid attachment or a point which has no thermal movement. The center of thermal fixity for each such wall will be at a common height above the tank bottom and horizontally aligned with the fixed point of the top determined by the expansion dome, namely the center point of the dome. Each planar wall array will further include a row of support assemblies extending horizontally away from the center of thermal fixity in both directions. Each support assembly in this row is a two dimension support assembly which permits movement only along the ramp, and the ramp member is rigidly attached to the tank with the ramp surface oriented horizontally away from the fixed point, that is, travel up the ramp is travel away from the center of thermal fixity. Each support assembly in this row provides vertical support for the tank wall, as vertical movement of

the wall relative to the support structure is not permitted. Each array for a cylindrical wall includes multiple points of thermal fixity, preferably located at or near the bottom of the wall. Each array for a cylindrical wall will include a multitude of two dimension and three dimension support assemblies disposed vertically in a pattern over the surface of the wall, preferably along a series of vertical lines spaced around the wall.

Each array for a planar wall or top also includes additional support assemblies according to this invention. Those additional assemblies may be either two dimension support assemblies, in which case the ramps are oriented radially away from the center of thermal fixity, or three dimension support assemblies, in which case the ramps are in horizontal rows and oriented horizontally away from a vertical line through the center of thermal fixity. Similar arrays may be used for the tank top.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

FIG. 1 is an exploded perspective view of a two member embodiment of a two dimension support assembly according to this invention.

FIG. 2 is a perspective view of a two member embodiment of a three dimension support assembly according to this invention.

FIG. 3 is an exploded perspective of a three-member embodiment of a three dimension support assembly according to this invention.

FIG. 4 is an elevation showing a preferred embodiment for interlocked attachment of either a two dimension support assembly or a three dimension support assembly to a tank wall or top and surrounding support structure. FIG. 4 also shows means of securing fitted insulation panels between flanges that retain support assemblies against tank and flanged collars secured to support assemblies.

FIG. 5 is a side view of a semi-membrane tank, surrounding support structure, and a first embodiment of an array of support assemblies according to this invention.

FIG. 6 is a side view of a semi-membrane tank, surrounding support structure, and a second embodiment of an array of support assemblies according to this invention.

FIG. 7 is a top view of a semi-membrane tank, surrounding support structure, depicting an embodiment which includes a radial array of support assemblies for the top of the tank.

FIG. 8 is a top view of wall assemblies depicting a preferred embodiment for a surrounding support structure that is attached to the outer member of several aligned support assemblies. FIG 8 further depicts vertical keys which attach to surrounding support structure for sidewalls and engage vertical keyways integral with an outer containment structure such as a ship structure.

FIG. 9 is an elevation showing another embodiment for interlocked attachment of either a two dimension support assembly or a three dimension support assembly to a tank wall or top and surrounding support structure.

Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

Support systems according to this invention include arrays of support assemblies, preferably two member support assemblies, distributed over the top and each side wall and connecting each wall or top to surrounding support structure by sliding engagement so as to permit each point of such engagement of assembly member attached to said wall or top to move inwardly perpendicular to the plane of the wall or top and toward the center of thermal fixity in the plane of said wall or top when the tank cooled, either from ambient temperature to below ambient temperature for a cold tank such as an LNG tank or from heated temperature to ambient temperature for a hot tank. This array may but need not include a fixed support at which each wall or top is rigidly attached to surrounding support structure. Depending on the design of the array and the orientation of the support assemblies, particular assemblies accommodate either one or two degrees of freedom parallel to the plane of the wall or top to permit the required movement. At least some of the support assemblies, which necessarily accommodate only one such degree of freedom, provide the vertical support required for each wall. Tops of semi-

membrane tanks most commonly have the center of thermal fixity at the geometric center of the top, where the expansion dome penetrates the tank.

FIG. 1 depicts a support assembly 1 according to this invention. Support assembly 1 is a two dimension support. It maintains rigid support between a tank wall or top while at the same time permitting thermally induced movement of the wall relative to the surrounding support structure only along the ramp, which, as previously explained, includes a component of movement perpendicular to the plane of a tank wall or top and a component of movement along a line in the plane of the tank wall or top parallel to the axis of the ramp. Support assembly 1 is shown disassembled. It includes a first member 2 and a second member 3 that may be slidingly engaged. One of members 2, 3 is fixedly attachable to a tank wall or top structure 7, and the other of members 2, 3 is fixedly attachable to the surrounding support structure 8. Attachment may be direct or indirect, as through load-bearing insulation.

Member 2 is a three dimensional elongated solid T-shaped piece wherein top portion 4 of the elongated "T" is ramped outwardly from element 8 as shown or, alternatively, from element 7 (not shown). Elongated portion 4 includes ramped surfaces 5 and 6. Member 3 is a solid piece that is complementary to member 2. It includes an elongated, T-shaped ramped recess 9 that is ramped outwardly from element 7 as shown or, alternatively, from element 8 (not shown). Recess 9 has top surface 10 that slidingly engages surface 5 of member 2 and bottom surfaces 11 that slidingly engages surfaces 6, whereby portion 4 can move along the ramp inside recess 9. Recess 9 has elongated sidewalls 12 that slidingly engage elongated sidewalls 13 of portion 4.

Member 3 surrounds portion 4 of member 2. Sidewalls 12 of member 3 prevent cross ramp movement. Bottom surfaces 11 interlock with bottom surfaces 6 to prevent relative movement of members 2, 3 perpendicularly to the ramp, that is, perpendicularly to the plane of the tank will or top except as occurs by sliding along the ramp.

Other means may be utilized to interlock members 2, 3 to prevent their separation perpendicular to the ramp. Preferred interlocking means, such as shown in FIG. 1, interlock members 2, 3 directly. Other such means would include, for example, T-shaped ramps not only for member 2, but also for member 3, flanges projecting outwardly from each ramp element 4, and slidingly engageable U-shaped members interlocking the

flanges of member 2 and the flanges of member 3. Less preferred interlocking means may be only indirectly connected to members 2, 3, as, for example, a tie bar angled between and pivotally secured to wall or top structure 7 and surrounding support structure 8 so as to hold members 2, 3 together but pivot as necessary so as not to prevent movement along the ramp of member 3 relative to member 2. When the U-shaped additional members are in place, or when tie bar or other indirectly connected additional member is in place, members 2, 3 are effectively interlocked.

It is important that the walls and top of a semi-membrane tank be thermally isolated from the surrounding support structure and any outer containment structure to prevent heat flow into a chilled tank or out of a hot tank. Conductive heat paths are minimized or, in preferred embodiments, eliminated to the extent possible. For this purpose, support assemblies may be made of insulating material, such as, for example, wood or wood composite material. Member 2, 3 may be fabricated from insulating material. However, portions of members 2, 3, particularly ramping faces 5, 6, 10, 11 may advantageously be metal, such as aluminum, steel or stainless steel. It is essential only that there be insulation blocking the thermal pathway between the tank and the surrounding support structure. Otherwise heat-conducting materials may be used without compromising thermal isolation.

FIG. 2 depicts a support assembly 21 according to this invention. Assembly 21 is an interlocked two-member, three dimension support assembly. It is constructed the same as support assembly 1 (FIG. 1) and operates the same with one exception, namely, that recess 9 is widened such that its elongated sidewalls 22 do not prevent, but rather permit, cross ramp movement to the extent calculated to be necessary by the designer, considering thermal contraction and expansion of the tank. Thus, orthogonal movement in the plane of the tank wall or top is accommodated. The embodiment shown in FIG. 2 is, as stated, a three dimension support assembly comprised of two members. Movement across the ramp may also be provided by means of a third member. Such an assembly according to this invention is shown in FIG. 3. Support assembly 31 comprises members 2, 3 as in FIG. 1 with the exception that member 3 additionally includes, proximate its away-from-the-ramp surface, grooves 33 and flanges 36 that project oppositely in the direction of the ramp axis. Fixedly secured to element 7, as shown or element 8 (not

shown) is third member 34, which includes spaced inwardly facing tabs 35 creating transverse slot 37 for slidingly receiving element 33, including flanges 36. Member 3 is thus permitted to move within member 34 parallel to the plane of the tank wall or top only in the cross ramp direction.

Members 3 can be adapted to secure, in whole or part, insulation panels to tank walls. One such adaptation is shown in FIG. 4. FIG. 4 is a section through support assembly 41, which may be either a two dimension support assembly, such as shown in FIG. 1, or a three dimension support assembly, such as shown in FIG. 2. As well a three-member three dimension support assembly (FIG. 3) could be substituted for two-member support assembly 41. Member 2 of assembly 41 is secured to surrounding support structure 8, for example, by welding or bolting. Base region 42 of member 3 is shaped to include flanges 43 projecting outwardly parallel to wall or top 7. Projecting outwardly from tank wall or top 7 are retainers 44 that include inwardly projecting tabs or flanges 45 for receiving base flanges 43, whereby member 3 may be fixedly secured to wall or top 7. Retainers 44 may comprise, for example, a single piece surrounding member 3 so as to prevent its movement relative to wall or top 7 in any direction. Surrounding member 3 is a U-shaped channel for receiving rigid or semi-rigid insulation panels 46. In this embodiment the U-shaped channel comprises flanged collar 47 secured to member 3 in cooperation with member 3 itself as the channel bottom and flanges (or flange) 43. By this arrangement panels 46 are retained outside the tank wall or top and parallel to its plane. Other adaptations to secure insulation panels utilizing members 3 are within the skill of the art.

Referring to FIG. 5, there is shown semi-membrane tank 51 in a cold condition having bottom 52, front-facing and rearwardly projecting sides 53 and top 54. Also shown for purposes of illustration are edges of sides and top 55 as they would be at ambient temperature. As shown in FIG. 5, walls 53 are joined one another and to bottom 52 and top 54 by radius edges 56 whose intersections are radius corners. Curve 60 represents the curvature of radius edge 56 in the cold condition at the midlength of the rearwardly projecting wall. Tank bottom 52 rests on load-bearing insulation 57. The surrounding support structure includes vertical members 58 spaced outwardly from walls 53 and horizontal members 59 spaced outwardly from top 54. The surrounding support

structure also includes horizontal members which are not shown for clarity of illustration. Shown in horizontal rows extending around sides 53 of tank 51 are support assemblies connecting sides 53 to vertical support members 58. One row, the bottom row in this embodiment, consists of two dimension support assemblies 1 (FIG. 1), placed horizontally and ramping away from the vertical midline of the wall, which extends downwardly from the midpoint of expansion dome 61. In assemblies 1, crosshatching indicates the degree member 2 has become offset from member 3 due to cooling of the tank. Assemblies closest to the midline of the wall have the least offset, and assemblies furthest away from the midline have the most offset. The row of assemblies 1 extending circumferentially around the tank provides vertical support for each tank wall. Represented by an "X" is point of thermal fixity 62 of front-facing wall 53. Additional rows of support assemblies are shown on walls 53. These are three dimension assemblies 21 (FIG. 2), also placed to ramp horizontally away from the midline, that is, the vertical line running through the point of fixity. In addition to having members 2, 3 offset along the ramp as shown by crosshatching, assemblies 21 have permitted thermal movement in the cross ramp direction (not shown). Shown above the tank, connecting top 54 to horizontal support members 59, is a row of support assemblies 21, placed vertically and ramping away from the midline of top 54 through the center of expansion dome 61. Here again there is more offset between members 2, 3 at the periphery of the tank than near the line through the point of fixity of the top, in this case the center of expansion dome 61. Support assemblies for tank top 54 can be arrayed in a grid pattern similar to the pattern depicted for front-facing wall 53. In that case support assemblies along the perpendicular lines passing through the point of fixity would be assemblies 1 passing ramped away from that point. Additional support assemblies would be assemblies 21 similarly to the arrangement shown for front-facing wall 53.

FIG. 6 shows an alternative embodiment of an array of support assemblies for wall 53 of tank 51 in the cold condition. This embodiment, like the embodiment shown in FIG. 5, includes a row of support assemblies 1 that are placed horizontally and ramp away from point of fixity 62. This embodiment further includes additional support assemblies 1 oriented such that they ramp away from point of fixity 62 in radial fashion. Although support assemblies 1 prevent cross ramp movement, the radial orientation

shown in FIG. 6 results in movement along the ramp having both a horizontal component and a vertical component parallel to the plane of the wall, thus allowing wall 53 to contract both vertically and horizontally toward point of fixity 62. It will be noted that in this embodiment radius edges 56 at top of tank 51 are basically uniform, and there is no distinctive curvature 60 at the midlength of the walls as there is in the embodiment shown in FIG. 5. Instead, in this embodiment the profile of the rearwardly projecting wall 53 at its midlength is shown by line 63.

FIG. 6 also shows a preferred way to construct an array of support assemblies for a cylindrical tank. FIG. 6 shows a vertical column of vertically disposed support assemblies 1 extending upwardly from point 62. For a cylindrical tank, the circle of thermal fixity would be a circle extending horizontally around the tank wall approximately through point 62. The vertical column of support assemblies 1 would be augmented by an additional vertically disposed assembly at or slightly above point 62. All other support assemblies in FIG. 6 would be replaced by additional vertical columns of support assemblies 1 spaced around the tank wall.

FIG. 7 shows an array of support assemblies 1 on tank top 54 in the cold condition. The array shown in FIG. 7 has assemblies 1 ramping radially away from point of fixity 62, which is the center of expansion dome 61. Also shown in FIG. 7 in cross section is the top row of support assemblies 21 (FIG. 5). In this view the increasing offset of members 2, 3 at the ends of tank wall 53 compared to the midline of the walls can be seen. The array shown in FIG. 7 is suitable for the circular top of a cylindrical tank as well.

We wish to note that the number of support assemblies shown in FIGS. 5-7 is not necessarily the number that would be used for an actual semi-membrane tank. The number and placement will vary depending upon design requirements.

FIG. 8 shows one sidewall 53 with surrounding support structure 58 and interconnecting support assemblies 21 (or 1) suitable for construction outside outer containment structure 80. The preassembly of a semi-membrane tank, surrounding support structure and interconnecting support assemblies can be hoisted by a crane and lowered into an outer containment structure such as an inner hull compartment of an LNG tanker. FIG. 8 shows an outer containment structure 80 fitted with a plurality of

vertical keyways 82. Although FIG. 8 shows structure 80 schematically as a wall with keyways, it will be appreciated that structure 80 could as well be multicomponent, as a hull or beam from which vertical supporting members having keyways 82 project inwardly toward surrounding support structure 58. FIG. 8 also shows a series of vertically extending keys 81 fixedly attached to surrounding support structure 58. FIG. 8 shows one key-keyway pair aligned with the center of thermal fixity, but that is not required. Our preferred construction is that keys 81 are themselves the vertical members of support structure 58. For ease of installation we prefer that keyways 82 and complementary keys 81 be tapered, that is, larger at the top of the tank. The keys and keyways can be reversed, that is, the keys may be on the outer containment structure and the keyways may be on the surrounding support structure. Keys and keyways can be interlocked in a variety of ways that are within the skill of the art. The system of keys and keyways is provided for at least two opposing planar sidewalls. It may be provided for some or all additional walls. For a cylindrical wall, the system of keys and keyways is provided for at least two opposing arc sections of the wall, and it may be provided for the entire periphery of the wall.

FIG. 9 is a section through support assembly 92, 93, 94, that is an alternative construction to that shown in FIG. 4. It may be either a two dimension support assembly, such as shown in FIG. 1, or a three dimension support assembly, such as shown in FIG. 2. As well, a three-member, three dimension support assembly (FIG.3) could be utilized. A two dimension support assembly is depicted. The support assembly comprises first member 92 that, similarly to member 2 of FIG. 4, is fixedly secured to the surrounding support structure, in this case structure 105, which may be the inner hull of a double-hulled tanker or a support structure member such as member 58 (FIG. 5); and second member 93 that, similarly to member 3 of FIG. 4, is fixedly secured to the outside of the semi-membrane tank, shown in FIG. 9 as curved-plate tank side 97, through load-bearing insulation block 94. The interface between members 92 and 93 is a ramping surface similar to the ramping construction shown in side view in FIG. 4. Support assembly member 93 is fixedly secured to insulation block 94 by one or more bolts 95. Attached to insulation block 94 are pairs of angled retainers 96 for receiving rigid or semi-rigid insulation panels 102.

The support assembly arrangement shown in FIG. 9 is particularly suited for use with semi-membrane tanks of curved-plate construction, described in U.S. Patent 5,727,492. FIG. 9 shows a portion of a vertical curved-plate tank wall or side 97 including a cusp 98 forming the juncture between two of the series of horizontally disposed curved-plate sections. Extending outwardly from cusp 98 and integral therewith or fixedly secured thereto is a shaped securing structure that fixedly engages insulation block 94, in this embodiment that shaped structure being T-bar 99, for attaching second member 93 to wall 97 at cusp 98. Insulation block 94 includes notch 100 shaped to conform to T-bar 99, which thereby fixedly secures the support assembly to cusp 98 of side wall 97. Optionally block 94 may be two piece, a dividing line 106 being shown in FIG. 9, securable to one another by a series of bolts such as bolt 95.

In the curved-plate embodiment shown in FIG. 9, the support assemblies are two dimension support assemblies, as the curved sections of tank wall 97 can flex to relieve stress in the vertical direction (the chords of the curved sections). Each horizontally extending cusp, being connected to outer support structure 105 by two dimension support assemblies that move in-out and laterally, is thus similar to the bottom row of assemblies 1 in FIG. 5 and, like assemblies 1, they provide vertical support for tank wall 97. Each wall 97 of a four-sided curved plate tank thus has a point of thermal fixity at a location along each cusp 98, generally in the horizontal center of the wall, in other words, a point 62 (FIG. 5) in each row of support assemblies, forming a vertical series of points 62. In each row support assemblies are placed to have ramp directions as shown for the bottom row in FIG. 5.

Rather than utilizing the ramp-enclosing sidewalls of member 93 to restrain vertical movement of cusp 98 and force vertical contraction and expansion to be accommodated by changes in the radius of the curved plates (sidewalls of two-dimension assemblies are shown as elements 12 in FIG. 1 and discussed above in the description of that figure), an alternative is to maintain the vertical separation between successive rows of support assemblies by other means. Shown in FIG. 9 is beam 103, for example an I-beam or an H-beam, which passes through hole 104 in member 93 and vertically through holes in members 93 in the column of assemblies at cusps above and below cusp 98 (not shown). Beam 103 is fixedly attached to members 93 in the column of assemblies.

Additional beams 103 are similarly disposed through and attached to other columns of assemblies (see FIG. 5) such that there is a series of beams 103 extending along each tank wall.

Beams 103 prevent cusps 98 from moving vertically with respect to one another, thereby forcing the curved plates in wall 97 to accommodate thermal expansion in the vertical direction. As will be appreciated, this will permit simplification of the ramp-enclosing construction shown in FIGS. 1 and 9, as cross-ramp movement need not be prevented thereby.

The series of beams 103 extending along each tank wall also provides a means for lifting the tank wall utilizing a lifting jig. An example of a lifting system is to provide each beam 103 with a hole 107 at its top such that a pipe can be slid through holes 107 on each tank side. The pipe (not shown) preferably comprises a detachable member of a lifting jig, but it could be slidably attached to beams 103. Utilizing the preferred embodiment, the tank, the support assemblies and beams 103 can be constructed and completely assembled outside the support structure. Assembly members 92 can be ramped inwardly toward tank wall 97 to provide installation clearance. The entire assembly can be lowered into the support structure, after which members 92 are ramped into engagement with outer support members 105 and secured thereto, as by welding.

A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. For example, such features as loose fits between interlocking support assembly members, adjustable tilting of sliding surfaces or other means to accommodate manufacturing tolerances or thermal gradients between different locations within a tank, constructing the mating surfaces of the ramps of metal attached to load bearing insulating blocks are all potential variations which are within the possible alternatives that would be readily apparent to a practitioner skilled in the art. Accordingly, other embodiments are within the scope of the following claims.